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Importance of ergonomic application for the improvement of coal productivity in mines

Netai Chandra Dey
Indian Institute of Engineering Science and Technology Shibpur, netaidey@hotmail.com

Shibaji Ch Dey

Gourab Dhara Sharma

IMPORTANCE OF ERGONOMIC APPLICATION FOR THE IMPROVEMENT OF COAL PRODUCTIVITY IN MINES

Netai Chandra Dey[1], Shibaji Ch. Dey and Gourab Dhara Sharma

ABSTRACT: The present study deals with the application of ergonomic intervention into a mining system with the view to increase its productivity. The effectiveness of the Ergonomic Work Rest Scheduling (EWRS) application, a vital tool of ergonomics, to reduce metabolic energy cost and increasing productivity with Effective Utilization of Man shift (EUMS) is the main focus of the study. Thirty five healthy underground trammers (N=35) were chosen based on some pre-determined criteria for the assessment. The personnel chosen from the mine were taken on the basis of experience of more than one year with no record of past illness. The study was performed in two different zones for one month of period each, one before application of EWRS and another after application of EWRS. Cardiac frequency of indirect physical parameters like Working Heart Rate (WHR) is recorded continuously at five seconds intermissions with a portable heart rate monitor. In case of Average Working Heart Rate (AWHR) value, it was seen that two different spells of after EWRS application value found lower than before EWRS application AWHR value. Different Cardiac Cost (CC) values like Net cardiac Cost (NCC) and RCC (Relative Cardiac Cost) also followed the trend of AWHR i.e. a significantly lower range after EWRS application. It was observed that application of appropriate EWRS has positively withdrawn the effect of the extra burden on mine workers. Perceived exertion scale had gone down to 13.91 as compared to before EWRS value of 15.11. It was also seen that application of EWRS effectively reduced the Net Metabolic Cost (NMC). The NMC of two different spells after application of EWRS seemed to be lower than that of Previous. After application of EWRS, NMC had gone down by 34.5% in the case of the spell 1and 38.1 % in the case of spell 2. Physiological job stress had been minimized by implementing adequate EWRS in between different working spells. Hence, it could be suggested that an implementation of EWRS and in depth ergonomic intervention would be very effective to minimize work-stress related problems and thereby increasing work efficiency and productivity of miners.

INTRODUCTION

Indian mining industries are one of the most powerful sectors which contribute towards the national energy demands since long. Indian mining industries have coal seams at such depth that it is not suitable for opencast mining and requires underground mining. In India the mining scenario differs from US and China (Singh R D, 1997). In a country like India, production from the manpower intensive underground mines is significantly low in comparison to open cast. The production from underground comes mainly from bord and pillar system (more than 90%). In deep mining, the room and pillar or bord and pillar method progresses along the seam. In the final stage of mining pillar extraction plays a major role. Apart from safety, the mining operations are also very hazardous and back breaking in nature (Dey *et al* 2015a; ILO, 2010**)**. A cross-section on available literatures on Indian miners has configured some serious job-stress related problems (Dey and Sharma, 2013; Dey *et al*, 2014, 2015b). Various standing postures as well as higher job demand in mining job pattern makes the work process harmful (Sharma *et al*, 2016, Saha *et al*, 2010) which is accounting for lots of ineffective times and affecting production loss.

Not only the aforementioned problem associated with mining, injuries are also one of the potent causes of disruption in production (Pingle, 2016). Because of the increasing number of injuries

[1] *Professor, Department of Mining Engineering, Indian Institute of Engineering Science and Technology Shibpur West Bengal, India Email: netaidey@hotmail.com Tel: 033 2668 4561 (ext. 475)*

caused by repetitive motion, excessive mechanical force, awkward postures, and application of Heavy Earth Moving Machineries (HEMM), ergonomics has become a most useful tool in the field of workplace safety. It is a process to look out an overall perspective for working layout in mining for suitable design of tasks, tools, equipment and most importantly fitting jobs to the miners. Body postures determine which posture of the body is going to be stressful and how much back strain will result for assuming awkward posture for a continuous time period. Spinal Discs mostly in the L5-S1 region is being affected when lifting, lowering or handling loads with the back bent or twisted for a continuous working shift. In the Indian mining industries there are many working groups like face drillers, roof bolters and dressers who are often used to work at or over shoulder height which could be stressful in particular. Implementation of ergonomically suitable postures with matching time exposure can reduce both the chances of injury and stress.

In fact; leading companies of the world are implementing agronomical measures into all of their operations to cope with the growing injuries along with the loss of production and productivity. Many of the national and international research studies have shown that application of ergonomics is really effective as far both the safety and productivity are concerned. The Washington State Department of Labor and Industries reviewed 250 ergonomic case studies to reveal the impact of ergonomics on business goals like cost savings, productivity and product quality (Middlesworth, 2016). From the previous research outcomes done on Applied Materials (supplier to the silicon chip industry) it was observed that properly designed and tested casters for manually moving 31.75 kN (7,000 lb) clean room manufacturing equipment increased productivity 400%, in terms of man hours, with reduced errors. Proactive Ergonomics culture in the industry emphasizes the deterrence of Work Related Musculoskeletal Disorders (WRMSDs) through recognizing, anticipating and reducing risk factors involved in a regular work culture reducing the chances of sickness absentees and herewith low productivity. Human factors and ergonomics are being implemented in the modern world as technological development focuses on the need of such requirements in daily work culture (Sanders and McCormick, 1993). Ergonomics application specially deals with five major improvement skills in industries. Many of the industries follow the beneficial goal point of these 5 skills and In this current research study application of EWRS and its effects on reducing energy cost and improvement in productivity is the main viewpoint.

Ergonomics has already been defined and its primary focus is on the design of continuous work activity that take place every day in mines. Fitting the job to the miners i.e. matching the requirements of a job with the capabilities of the worker with proper EWRS are the approaches to be adopted in order to lessen the risks of injuries resulting from non-ergonomic work culture in the present context of Indian mining. The present study deals with the application of ergonomic intervention to increase productivity in the industry. The initiative is taken by considering the EWRS introduction in between each and every working spell. The effectiveness of ergonomic EWRS application in mines to reduce metabolic energy cost and Cardiac Cost (CC) of miners are the main ergonomic viewpoints of the study. The goal of application of EWRS is to provide maximum productivity with minimal cost; in this context cost is expressed as the working Energy Expenditure (EE) of a worker. In a workplace setting there are seldom a large number of tasks that exceed the capabilities of most of the work force. There may be jobs that will include a specific task that requires extended reaches or overhead work that cannot be sustained for long periods, by using EWRS principles to design these tasks; more people may be able to perform the job without facing high EE demand and risk of injury.

METHODOLOGY AND INSTRUMENTATION

Description of mines

Study has been conducted in a mine of Coal India Limited in Jharkhand, India. The mine is of degree II gassiness which produces 1 m^3 of inflammable gas per ton of coal produced having an inclination of 1 in 10 at a depth of 150 m. This mine has no shaft to descend and workers have to reach the working site by walking through the incline.

Selection of subjects

Thirty five healthy individuals (N=35) are chosen for the assessment. The proposed study was so schemed that a maximum gain can be achieved. The subject group is selected with the persons who were willing to participate in the study and after getting official permission from the Colliery Manager. The chosen personnel of underground trammer from the mine are taken on the basis of experience of more than 1 year. All the chosen workforce had no record of past illness.

Brief overview on underground tramming operation

Blasted and dressed coal is lifted into tubs (each one ton capacity) and dispatched to the surface via a haulage network. The empty tubs are supplied to the face by the trammers with the help of tugger haulage inside the working panel and loaded coal tubs are taken out from the underground panel and hauled up by the direct (main) rope haulage right up to the surface.

Principal Working Methodology

The working methodology is based on the improvement of productivity with application of the EWRS technique. Cardiac frequency of indirect physical parameters like Working Heart Rate (WHR) is recorded continuously in five second intermissions in two spells with a portable heart rate monitor (Sports Tester Polar Electro CS 400, Finland) by placing the machine on the trans-thoracic region of the subject before they go down to the working site. NCC and RCC are the most important derived parameters of WHRs which mirrors the cardiac strain intensity. The maximum heart rate of the subject is calculated by following the formula of American Heart Association (AHA, 1972). Determination of NMC (Ayoub, 1989) and EE (Datta and Ramanathan, 1969) are performed by the formula proposed by different scientists. In fact the study was performed in two different zones for one month each, one before application of EWRS and another one after application of EWRS. To fit with the perceived exertion scale, Borg physiological exertion scale is fixed with both the working experimental zone and the perceived exertion is measured in both of the cases i.e. before and after EWRS application. Significant changes in cardiac stress parameters and energy expenditure after application of EWRS are measured. Along with the Cardiac Frequency (CF) measurement the changes in NMC is also determined in two different experimental zones to find out the relationship between low NMC and high productivity.

Statistical Analysis

Mean and standard deviation are calculated for each set of data. Each set of data consists of spell 1 and spell 2 and before application of EWRS spell 1 variable dataset has been compared with after application of EWRS spell 1 dataset. Difference between mean values have been estimated from two different sets of data which are tested by one tail Pierson's' test (homoscedastic) with a significance level of 'p'= 0.05 and 0.0001.

Results and Observations

Results have been considered in two different application contexts one is before the application of EWRS and another is after application of EWRS. Table 1 suggests that in the case of AWHR values two different spells of before EWRS are higher than of after application AWHR. According to the workload classification of AWHR by Astrand (Astrand *et al,* 2003), it is seen that with the application of EWRS the workload is going down from very heavy workload category to heavy category. Different cardiac Cost (CC) value like NCC and RCC are also reduced significantly with the application of EWRS. Hence it is almost certain that EWRS has positively withdrawn the effect of the extra burden on mine workers.

Another significant stress estimation scale i.e. Rate of Perceived Exhaustion (RPE) are also showing positive effect on application of EWRS. Here it is clearly seen that after the application of EWRS, the perceived exhaustion scale went down to 13.91 as compared to previously 15.11.

Table 1: Effective parameters before and after application of EWRS

Parameters	Before application of EWRS		After application of EWRS		t-test Homoscedastic one tail	
	Spell 1 (N=35) [Mean + SD]	Spell 2 (N=35) [Mean + SD]	Spell 1 (N=35) [Mean + SD]	Spell 2 (N=35) [Mean + SD]	Spell 1 Vs. Spell 1	Spell 2 Vs. Spell 2
PWHR(bpm)	79.3+ 3.35	80.71+ 3.82	79.5 +3.4	88.35+ 16.93	NS	NS
AWHR(bpm)	132.07+ 9.03	142.16+7.91	119.01 +13.84	125.64+18.25	<0.0001	<0.0001
NCC(bpm)	64.64+11.47	74.73+10.88	51.75+ 11.21	58.38 +16.64	<0.0001	<0.0001
RCC (%)	62.89+10.4	72.76+9.53	50.54+11.04	56.91+15.41	<0.0001	<0.0001
Peak HR(bpm)	156.74+14.14	171.20+15.14	129.74 + 17.5	134.03+21.3	<0.0001	<0.0001
RPE	14.83+3.29	15.11+2.70	14.14+2.99	13.91+2.69	NS	<0.05

Application of EWRS and Energy cost

Energy Cost (EC) is an important feature of long duration work. It is believed that ECis the outcome of physical hurdles, which the body faces. In Table 2 it is seen that application of EWRS effectively reduces the Net Metabolic Cost (NMC). Here the NMC of two different spells after application of EWRS seems to be lower than that of previous tests.

Table 2: Energy cost before and after application of EWR

Parameters	Before application of EWRS		After application of EWRS		t-test Homoscedastic one tail	
	Spell 1 (N=35) [Mean + SD]	Spell 2 (N=35) [Mean + SD]	Spell 1 (N=35) [Mean + SD]	Spell 2 (N=35) [Mean + SD]	Spell 1 Vs Spell 1	Spell 2 Vs Spell 2
EE(kcal/min)	5.70+0.58	6.28+0.68	4.77+ 0.52	4.98+0.70	<0.0001	<0.0001
NMC(kcal/min)	4.09+0.72	4.67+0.75	2.68+0.52	2.89+0.70	<0.0001	<0.0001

The implementation of the EWRS shows a positive impact as the EC of spell 2 has been reduced significantly (<0.0001) in both cases (Table 2). The implementation of EWRS in between the working spell effectively reduces the NMC (see Figure 1). EWRS technique is applied to the same workforces and shows that NMC has gone down by 34.5% in case of spell 1 and 38.1 % in case of spell 2 respectively. The rest allowance formula proposed by Spitzer (Ayoub, 1989) is: R= (M/4-1) ×100, where, R=Resting time as a % of working time, M= Net metabolic cost (kcal/min) = (Total energy cost-resting energy cost). If NMC is considered as the rest pause variables then based on Spitzer a significant reduction in NMC is observed after EWRS as compared to before EWRS. Specifically before EWRS, NMC remains at a value that is higher than 4 kcal/min. It indicates a need of a rest pause. Reduction of NMC to below 4 kcal/min is possible with implementation of EWRS where there is no requirement of rest–pause. This will be increasing the working time of the miners and thereby with good impact on the time of Effective Manpower Shift (EMS) and productivity of the mine.

Different working spells in mines have different augmentation of work demand and the EC depends on work nature. Figures 2 and 3 show NMC differences in spell 2 and 3 respectively.

According to the American conference for governmental industrial hygiene, the EE of two different spells for EE before application of EWRS are showing the value indicating the Moderate work intensity to Heavy while after application of EWRS the same workforces are tested and is found below the range of moderate intensity (ACGIH, 2012) i.e. light to moderate working intensity (Table 2).

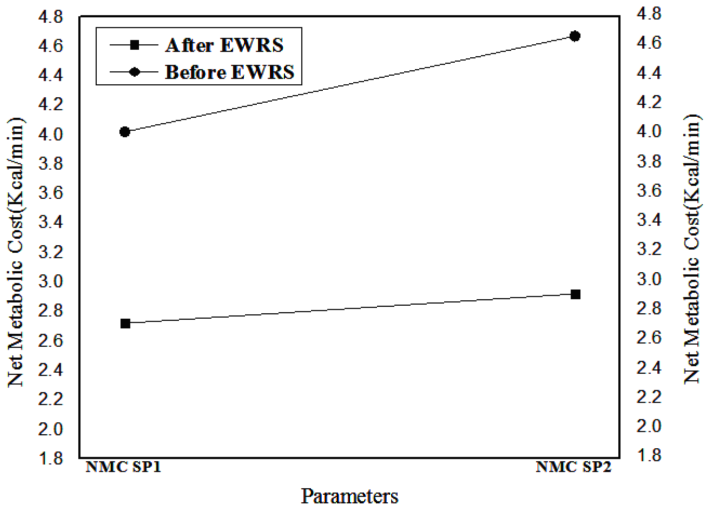

Figure1: Difference of NMC before and after application of EWRS

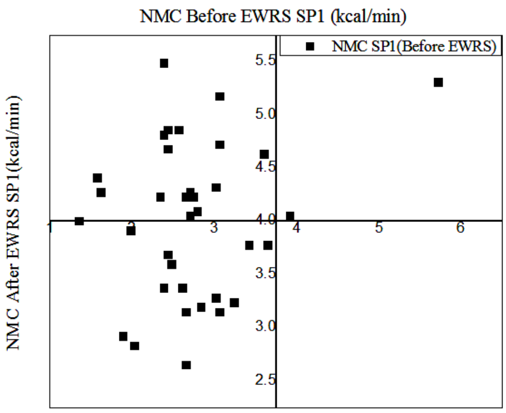

Figure 2: NMC differences in spell 1

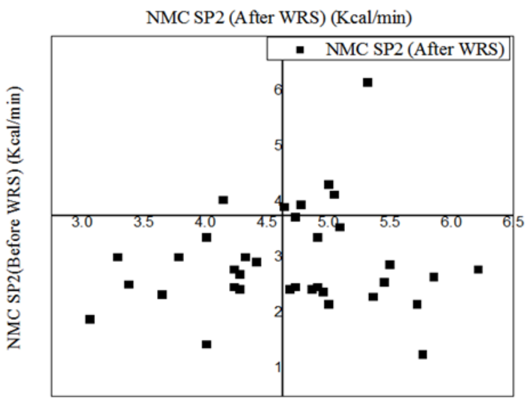

Figure 3: NMC differences in spell 2

Schematic model of change

Figure 4 shows the schematic model of effects of EWRS.

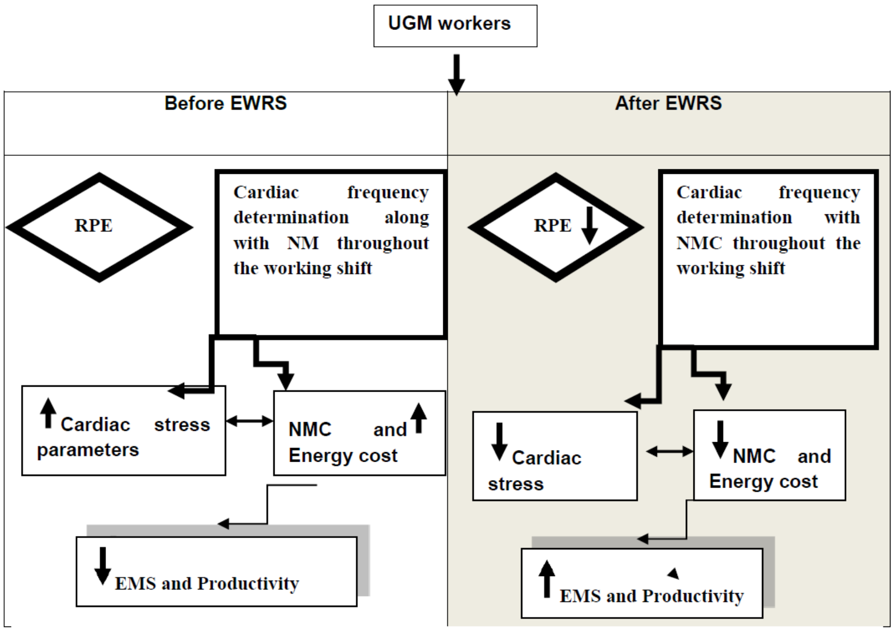

Figure 4: Schematic model of effect of EWRS

DISCUSSION

Having considered the importance and rising productivity related problems in Indian mines along with high EC, this study on EWRS application provides basic and proven information aiming at improving productivity and EMS efficiency. Moreover, EMS efficiency improvement can also reduce production cost and increase productivity onto a certain level. In mining like other industries exposure to a bad workplace design and hostile working environment maximally affect the workers. Handling of face loading machines in underground and heavy earth moving machines in open cast mines also causes direct exposure to vibration. In this study underground tramming operation had been considered and it is seen that the physiological EC in between the spells is very high which requires a rest pause of some extend. Job profile of underground trammers in Indian mining mostly requires continuous work pattern without having a proper work rest schedule. In Indian underground coal mines, comfortable operating conditions are very difficult to maintain due to varying geo-mining conditions within the ambit of desired muscle efficiency for 8 hr shift. Working pattern is thus responsible for development of musculo-skeletal disorders with early onset of fatigue. Ergonomic intervention in the form of implementation of EWRS for one month of time has reduced the NMC significantly ($p<0.0001$). The mean NMC is achieved about 32.3% and 37% less with application of EWRS in mines for two different working spells. Perceived exertion for those mine workers are achieved in between Maximal Heart Rate (MHR) of 70-80%, which is considered as very high working intensity (Borg, 1982). Therefore, it is obvious that the workers are facing high job stress in mines every day. Appropriate static cardiovascular functioning is very important to carry out work in hot and humid working conditions where changes in body function directly reflect on WHR (Biswas *et al*, 2011). The different spell of WHR and NMC (Figures 2 and 3) are showing the augmentation in physiological job demand and work-stress regimen. Importance of WHR imposes greatly to select derived heart rate parameters like NCC, RCC and EE, which plays an important role to detect physiological job demand. In this present study it is noticed that the WHR and other derived parameters like NCC (Lablache-Combier and Ley, 1984**)**, RCC (Chamoux *et al*, 1985), and EE showed a high range than the normal recommended value.

Excess demand of energy as well as high CF increases the EE and heart rate profile to minimize the increasing job demand. The body generally increases the blood flow to cope with working efficiency levels. Higher job stress, high mechanical efficiency, higher CF requires high energy output for a continuous time of 8 hours, which is practically impossible to sustain under hot and humid working condition. Short spells with adequate rest pause break i.e. EWRS application makes it smooth and regular in Indian mines which reduces not only the NMC but also the RPE. The present study indicates that application of EWRS reduces the perceived exertion from heavy-moderate category to moderate -light intensity.

Perhaps most importantly, the findings of this study have shown that Indian mining firms may benefit substantially by improving Effective Manpower Shifts (EMS) to enhance the productivity with appropriate EWRS application programs. In contrast, the benefits of applications of ergonomic intervention are clear not only by reducing pain and the EC but also with enhancing productivity. Study results suggest that ergonomic intervention in mine workplaces alone provide a sustainable productivity benefit.

CONCLUSION

The study concludes that the physiological job stress and energy cost could be minimized significantly by implementing EWRS in between different working spells in mines. The study has shown the high range of cardiac strain through NCC and RCC parameters which are beyond the normal recommended value. NCC and RCC values are high because of bad workplace design and improper work-rest scheduling in between the different working spell of a single individual. Cardiac stress parameters along with energy cost parameters go down after implementation of EWRS measures.

High CF, RPE and NMC go down to significant level, which will pose an optimistic effect on psycho-physiological condition of a miner which possibly reflects a positive way to EMS and productivity of a mine. Therefore, it can be suggested that an implementation of EWRS and in depth ergonomic intervention would be very effective to minimize EC along with other EMS related problems as well as to increase miner’s efficiency, effective working time and ultimately productivity of a mine.

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